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CARRIERS OF PHOSPHORUS IN FERTILIZERS

BY CHAS. E. THORNE

The chief sources from which the phosphorus of commercial fertilizers is derived are acid phosphate on the one hand and bone meal or other animal refuse on the other. Acid phosphate, known in England as superphosphate, is made by mixing together approximately equal weights of the phosphatic rock, found in Tennessee, Florida and South Carolina, and sulphuric acid, the object of adding the acid being to produce a chemical action by which the almost insoluble rock is converted into a form soluble in water or in very dilute acids. The rock is first ground to a very fine powder, called floats; this is mixed with sulphuric acid, the mixture is allowed to stand for some time when it becomes caked, it is then reground and sold, sometimes simply as acid phosphate, more often under some proprietary name, as "Dissolved Bone," "Wheat Special," "XXX Phosphate," etc., etc. Any fertilizing material, which is claimed to contain only phosphoric acid, of which 10 to 16 percent is classed as "available" and 1 to 3 percent as "insoluble" may be set down as an acid phosphate.

The term "phosphoric acid" is a misnomer, as the acidity of an acid phosphate is due to the sulphuric acid of the fertilizer, and not to the combination of phosphorus with oxygen formerly named "phosphoric acid," but now more correctly called phosphorus pent-oxide.

Bonemeal is sold as "pure raw bonemeal," which should analyze 3 to 5 percent "ammonia" and 20 to 24 percent "phosphoric acid," and as "steamed bonemeal," analyzing 1 to 3 percent "ammonia" and 20 to 27 percent "phosphoric acid," both grades varying occasionally from these figures.

A third bone fertilizer, formerly much more in use than at present, was made by treating bone charcoal which had been used in refining sugar, oil etc., with sulphuric acid, making what is known as "dissolved boneblack," a material closely approximating acid phosphate in composition.

In addition to these carriers of phosphorus the untreated, ground phosphate rock, or "floats," is offered for fertilizing purposes, and also a fourth material known here as Basic Slag, and in Europe as "Thomas Phosphate Powder." This substance is a by-product of the manufacture of steel by the Basic or Thomas-Gilchrist process, a process by which the phosphorus of phosphatic iron ores is caused to unite with the furnace slag, which is then ground into a fine powder. Basic slag phosphate is not now being manufactured in this country, our entire supply coming from Europe.

While located at Columbus, this Station began a comparison of dissolved boneblack, acid phosphate and basic slag as carriers of phosphorus; these materials being used in combination with nitrate of soda and muriate of potash, the fertilizers being so compounded as to carry equal weights each of phosphorus, potassium and nitrogen. The fertilizers were used on crops grown in continuous culture, with the following outcome:

TABLE I:—CARRIERS OF PHOSPHORUS ON CROPS GROWN IN CONTINUOUS CULTURE AT COLUMBUS, 1888--1902

Carriers of phosphorus	Increase per acre					
	Corn 13-year average		Oats 8-year average		Wheat 12-year average	
	Grain	Stover	Grain	Straw	Grain	Straw
	Bus	lbs	Bus	lbs	Bus	lbs
Dissolved boneblack.........	6.42	390	6.21	434	5.93	1,144
Acid phosphate.............	8.29	678	6.58	537	4.22	673
Basic slag	7 78	499	6 58	496	5.14	697

In the case of the wheat crop the fertilizers were discontinued after the eighth season, but the yields were separately ascertained for six years longer. In 1896 and 1900 the wheat was totally destroyed in this experiment by Hessian fly and winter killing, and the averages are computed for 12 years.

On the removal of the Station to Wooster this comparison was begun again, but this time on crops grown in rotation instead of in continuous culture—the 5-year cereal rotation of corn, oats, wheat, clover and timothy, begun at Wooster in 1894 and at Strongsville in 1895, and the 3-year rotation of potatoes, wheat and clover begun at Wooster in 1894. Bonemeal was added to the test in each case and the phosphates were used in complete fertilizers, made up to contain equal weights of nitrogen, phosphorus and potassium, acid phosphate being used on the basis of 14 percent available phosphoric acid and dissolved boneblack on that of 16 percent, while bonemeal was reckoned as containing the equivalent of 20 percent "available" phosphoric acid and basic slag as containing the equivalent of 17 percent total phosphoric acid. The general results of this comparison are shown in Table II, which gives the total yield per acre from each of the different applications and the increase over the unfertilized yield.*

TABLE II:—COMPARISON OF CARRIERS OF PHOSPHORUS.
TOTAL YIELD AND INCREASE PER ACRE

Plot No	Carrier	Corn		Oats		Wheat		Hay	
		Grain Bus	Stover lbs	Grain Bus	Straw lbs	Grain Bus	Straw lbs	Clover lbs	Timothy lbs
	5-year cereal rotation: Wooster: 15-year average total yield per acre								
11	Acid phosphate	48.44	2,273	49.86	2,155	27.03	2,846	3,123	3,620
26	Bonemeal	46.91	2,319	46.71	1,970	23.49	2,372	3,293	3,677
27	Dissolved boneblack	48.22	2,307	49.35	2,163	26 36	2,639	2,893	3,488
29	Basic slag	49.33	2 410	47.42	2 012	24.61	2,518	3 064	3 835
	5-year cereal rotation: Wooster: 15-year average increase per acre								
11	Acid phosphate	18.07	668	18.33	901	16.30	1,766	1,317	1,058
26	Bonemeal	14.18	542	14.98	673	12.69	1,282	1,468	949
27	Dissolved boneblack	14.73	501	17 22	881	15.65	1,589	1,023	683
29	Basic slag	15.09	576	14.90	744	13.98	1,506	1 148	952
	5-year cereal rotation: Strongsville: 14-year average total yield per acre								
11	Acid phosphate	37.33	1,920	50.93	2,013	18.43	1,765	2,496	2,659
26	Bonemeal	34.62	1,934	47.66	1,826	19.44	1,763	2,614	2,356
27	Dissolved boneblack	33.87	1,869	48.42	1,846	18.37	1,700	2,278	1,970
29	Basic slag	35.34	1 896	46 93	1 775	19.58	1 808	2 342	2 269
	5-year cereal rotation: Strongsville: 14-year average increase per acre								
11	Acid phosphate	11.76	439	13.93	583	10.61	1,026	821	482
26	Bonemeal	8 84	339	12.20	469	11.69	1,047	925	460
27	Dissolved boneblack	8.90	304	13.59	559	10.50	970	638	148
29	Basic slag	10.95	360	13.16	539	11.85	1 090	762	502

3-year potato rotation: Wooster: 15-year average yield and increase per acre

Plot No	Carrier	Potatoes		Wheat				Clover	
				Yield		Increase			
		Yield Bus	Increase Bus	Grain Bus	Straw lbs	Grain Bus	Straw lbs	Yield lbs	Increase lbs
11	Acid phosphate	184.08	24.18	38.61	3,720	9.29	1,003	3,492	373
26	Bonemeal	176 48	28.31	35.64	3,351	10.85	1,025	3,424	654
27	Dissolved boneblack	182 98	34.18	36 95	3,631	12.12	1,253	3,252	417
29	Basic slag	180.87	31.45	37.61	3 736	12.75	1 315	3,714	861

Table II shows that in the 5-year cereal rotation at Wooster the corn and timothy have given slightly larger total yields on the plot receiving basic slag, while the other crops are larger on the ones receiving acid phosphate. The increase, however, is greater from the acid phosphate in every case.

*In all the experiments with fertilizers conducted by this Station every third plot is left continuously without either fertilizers or manure, and the increase is computed on the assumption that if the yield of Plots 1 and 4, unfertilized, were 30 and 33 bushels, respectively, the unaided yields of Plots 2 and 3 would probably have been 31 and 32 bushels.

At Strongsville all the crops except wheat show a larger total yield from the acid phosphate, and all except wheat and timothy show also a greater increase.

In the rotation at Wooster of potatoes, wheat and clover, the total yields of potatoes and wheat are greater after acid phosphate, and of clover after basic slag; the increase, however, is greater in every case after the slag.

The soils upon which the two cereal rotations are located are of low fertility and are quite uniform in character. The potato rotation, however, is located upon a comparatively fertile soil, the 15-year unfertilized yield of potatoes having been 160 bushels per acre, and that of wheat 26 1-2 bushels, whereas the yield of wheat in the cereal rotations has been but 10 1-2 bushels for the same period at Wooster and 7 bushels for the 12 years during which wheat has been grown at Strongsville.

As there is a limit to the normal size of every plant, so there is a limit to its acre yield, and the nearer this limit is approached the greater the difficulty in producing further increase. For example, it is far easier to raise the yield of wheat from 10 bushels per acre to 30 bushels, than to raise it from 30 to 40 bushels. In the potato rotation at Wooster the unfertilized yields with which the yield of Plot 11 is compared are considerably greater than those adjoining Plots 26, 27 and 29, and this may explain the relatively greater increase found on these plots by our method of computation.

In Table III is given the value for each rotation of the total yield and of the increase, as found by computing corn at 40 cents per bushel, oats at 30 cents, wheat at 80 cents, potatoes at 40 cents, stover at $3.00 per ton, straw at $2.00 and hay at $8.00.

TABLE III:—VALUES OF TOTAL PRODUCE AND INCREASE FOR EACH ROTATION FROM DIFFERENT CARRIERS OF PHOSPHORUS

Station and carrier	Plot No	Value per acre for one rotation	
		Total	Increase
Wooster: Cereal rotation:			
Acid phosphate	11	$ 91.34	$38.94
Bonemeal	26	87.27	32.75
Dissolved boneblack	27	88.97	33.62
Basic slag	29	89.38	33.20
Strongsville: Cereal rotation:			
Acid phosphate	11	72.23	24 85
Bonemeal	26	70.07	24.11
Dissolved boneblack	27	66.11	21.17
Basic slag	29	68.75	25.03
Wooster: Potato rotation:			
Acid phosphate	11	122.21	19 60
Bonemeal	26	116 15	23 64
Dissolved boneblack	27	119.39	26 29
Basic slag	29	121 03	27.54

In the two cereal rotations the variations in the total and increase values are similar. In the potato rotation Plots 26, 27 and 29 show similar variations, indicating that the low increase found on Plot 11 is due to the cause above suggested.

The experiments at Wooster and Strongsville have been made on acid soils, and it is important to know whether like results would be obtained on soils of a different character. The experiment at Columbus is a partial answer to this question, but we have a little further light in the experiments on liming the soil which have been conducted on the cereal rotation at Wooster since 1900, when the plan was adopted of applying lime to one half of each of the five 30-plot sections included in the experiment, as it came under the corn crop, the lime being applied to fertilized and unfertilized plots alike. The crop of 1903 was so nearly a failure that the limed and unlimed halves were not harvested separately, but for the other four years of the period, 1900-1904, the yields have been as shown below:

TABLE IV:—YIELDS OF *CORN* FROM DIFFERENT CARRIERS OF PHOSPHORUS

Plot No	Carriers of phosphorus	Yield		Increase	
		Unlimed	Limed	Unlimed	Limed
		Bus	Bus	Bus	Bus
11	Acid phosphate...............	53.50	61.00	23.42	22.16
26	Bonemeal.....................	53.14	60.91	20.56	20 29
27	Dissolved boneblack..........	54.64	61.09	21.84	21.15
29	Basic slag...	52.66	58.36	19 64	19 10

It does not appear that the liming has materially affected the comparison, so far as the corn crops were concerned. The oats, wheat and timothy unfortunately were not separately harvested during the first few years of this test, except the oats crops of 1901 and 1905. The tables below give the results for the seasons when the yields were separated:

TABLE V:—YIELD OF *OATS* FROM DIFFERENT CARRIERS OF PHOSPHORUS. AVERAGE OF 2 CROPS GROWN IN 1901 AND 1905

Plot No	Carriers of phosphorus	Yield		Increase	
		Unlimed	Limed	Unlimed	Limed
		Bus	Bus	Bus	Bus
11	Acid phosphate...............	59.92	58.51	30.21	17.92
26	Bonemeal.....................	55.62	55.54	23.46	15.05
27	Dissolved boneblack..........	58.27	58 59	25.13	17.37
29	Basic slag....................	54.61	59.29	20 48	17.34

In the case of the oats crop the liming seems to have caused a relative increase in the effectiveness of the slag phosphate—just the opposite of what would be anticipated, if the additional lime carried by the slag is of material advantage on acid soils.

Table VI gives the average yields of the five crops of clover hay—1900 to 1904 inclusive—following the liming:

TABLE VI:—YIELDS OF *CLOVER* FROM DIFFERENT CARRIERS OF PHOSPHORUS

Plot No	Carriers of phosphorus	Yield		Increase	
		Unlimed	Limed	Unlimed	Limed
		Tons	Tons	Tons	Tons
11	Acid phosphate	1.43	1.92	0.70	0.79
26	Bonemeal	1.51	2.08	0.76	0.96
27	Dissolved boneblack	1.19	1.96	0.43	0.74
29	Basic slag	1.44	1 75	0.65	0.59

The clover crop shows practically the same yield but a smaller increase after the slag than after the acid phosphate on the unlimed land, and a smaller yield and increase on the limed land. As stated further on, however, the hay weights do not show the full effect of the different carriers on the clover.

The acid phosphate used in this trial has been the commercial grade, sold to contain 14 percent available phosphoric acid as the minimum. The basic slag has been sold to contain 17 percent and over of total phosphoric acid. The acid phosphate has been used at the rate of 320 pounds for each rotation—80 pounds on corn, 80 pounds on oats and 160 pounds on wheat. The basic slag has been used at the rate of 260 pounds for each rotation, 65 pounds each on corn and oats and 130 pounds on wheat, thus giving a total of 44.8 pounds of phosphoric acid in the acid phosphate and 44.2 pounds in the slag, on the basis of the claimed composition.

Associated with the phosphates has been a total of 480 pounds of nitrate of soda—160 pounds on each crop—and 260 pounds of muriate of potash—80 pounds each on corn and oats and 100 pounds on wheat. The fertilizer would therefore have an average percentage composition of about 8 1-2 percent "ammonia," 4 1-5 percent "phosphoric acid" and 12 percent "potash," thus giving such a surplus of nitrogen and potassium that there could be no possibility of the action of the phosphates being limited by lack of these elements. That no such limitation occurred is shown by the outcome on Plot 17 in these tests, a plot which has received, for each rotation, 240 pounds of nitrate of soda, or one half the quantity given to Plot 11 and the other plots in the phosphate comparison, with 480 pounds of acid phosphate, or 50 percent more than that given the other plots, and the same quantity of muriate of potash. The yields of Plots 11 and 17 are compared in Table VII:

TABLE VII:—COMPARISON OF PLOTS 11 AND 17: YIELDS PER ACRE

Crop	Unlimed		Limed	
	Plot 11	Plot 17	Plot 11	Plot 17
Corn, bushels	53.50	48.98	61.00	63.48
Oats, "	59 92	58.90	58 51	61.32
Clover hay, tons	1.43	1.14	1.92	2.07

On the unlimed land Plot 17, with its smaller allowance of nitrogen,gives a smaller yield than Plot 11; but when lime is added nitrification in the soil is accelerated and Plot 17, with its larger supply of phosphorus, passes Plot 11 in yield of all the crops except wheat.

The dissolved boneblack used in this test was purchased in ready-mixed form at the outset, but later on it became difficult to secure it in this form and it was mixed for the purpose from bone charcoal and sulphuric acid. It is possible that we did not secure as perfect a combination of the two materials as is done when they are mixed in larger quantities and allowed to stand for a considerable time before use, and therefore the sulphuric acid may have been liberated in the soil more readily, thus tending to increase the soil acidity to a greater extent than the acid phosphate. It is true that the clover weights, as given in the table, show but little difference between these two carriers; but as seen in the field it has been evident that Plot 27 carried much less clover than either of the other three, and that a larger part of the weight harvested from it consisted of weeds. Throughout the later years of the test the superior growth of clover on Plots 26 and 29 has been very conspicuous, as compared with Plot 27; but Plot 11 has fallen but little behind in this respect.

Up to 1905 the bonemeal used in this test was raw bonemeal, being used at the rate of 220 pounds for each rotation; but in the spring of that year and since steamed bonemeal has been used, at the rate of 180 pounds per acre, a comparison at Strongsville of the two bonemeals having indicated that the steamed meal is the more effective carrier of phosphorus.

The basic slag used in the earlier and latest experiments was of German manufacture. In 1906 a slag of American manufacture was substituted. Our analyses of the German slag indicated an average of barely 17 percent total phosphoric acid. The American slag showed 19 percent. As this material is no longer manufactured in America we have been compelled to return to the German slag in order to continue the experiment.

CONCLUSIONS.

The outcome of the 20 years' work summarized in the preceding pages seems clearly to indicate that acid phosphate has been the most effective of the four carriers of phosphorus employed in these experiments for the cereal crops, while bonemeal and basic slag were preferable for clover on acid soils. When, however, the matter is considered from the standpoint of a complete rotation, embracing both cereal crops and clover, it appears that on these acid soils the utmost that can be claimed for basic slag is that its total phosphorus has been of equal effect with the available phosphorus in acid phosphate, or the phosphorus in fine bonemeal, pound for pound, and that no additional value can be ascribed to the basic slag because of the lime or other substances which it may have contained; while on soils that have been limed the pound of total phosphorus in basic slag has been less effective than the pound of available phosphorus in acid phosphate or in fine bonemeal.

It will be observed that in all these experiments the various phosphate carriers have been used in conjunction with nitrate of soda, but other experiments have shown that on acid soils nitrate of soda is a more effective carrier of nitrogen than the organic carriers (animal refuse, oilmeals, etc.) usually employed in the compounding of commercial fertilizers. In the absence of nitrate of soda, therefore, it is possible that basic slag would be relatively more effective on acid soils than it has appeared to be in the experiments above reported.

Since, however, nitrogen may be purchased in nitrate of soda more cheaply than in the average ready-mixed fertilizers this point is of little practical importance.

While these experiments would indicate that it would be possible to correct soil acidity by the use of basic slag, yet this would be an expensive method, for a ton of quicklime should neutralize as much acidity as three tons of basic slag, and over most of Ohio the cost of a ton of quicklime will not exceed one-third that of a ton of basic slag.

There is reason to believe that acid phosphate increases the tendency to soil acidity, but it is not the sole cause of such acidity, for there are very acid soils which have never received any acid phosphate. On such soils it is necessary to correct the acidity before they will yield a full harvest, and lime is the cheapest material for this purpose; but the additional amount of lime required to neutralize the sulphuric acid in an ordinary dressing of acid phosphate is a very small quantity.